Reduction of Scrap in the Extrusion Process

LIJIN

ROADMAP

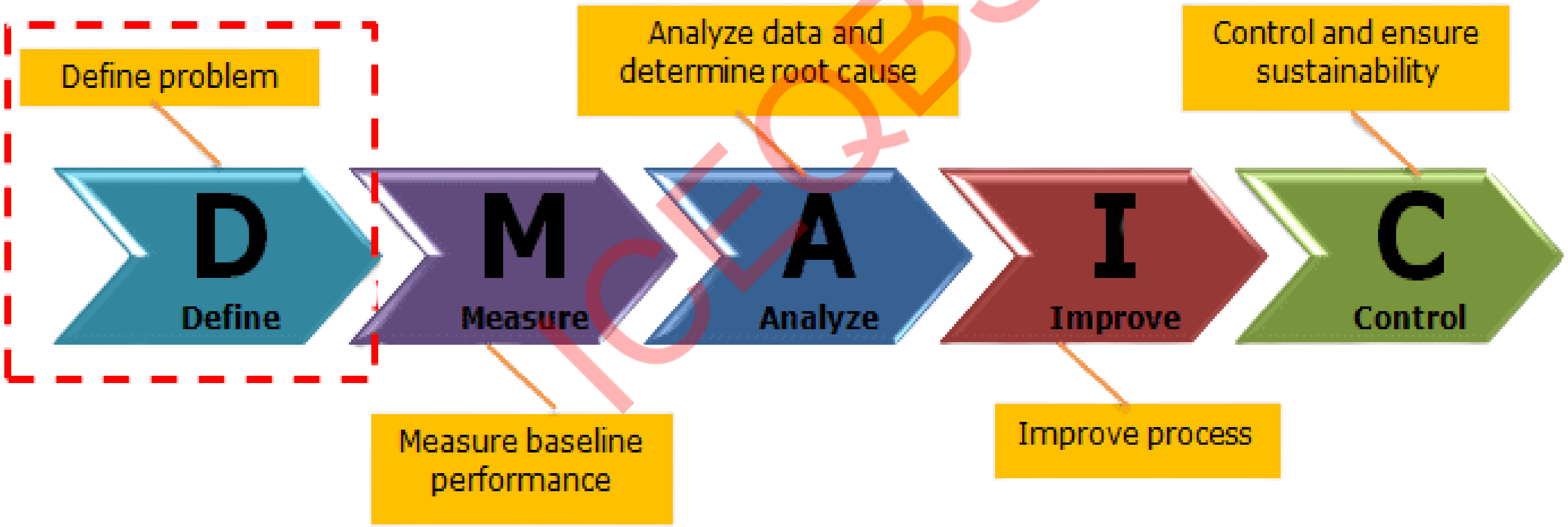
- Overview
- Define
- Measure
- Analyse
- Improve
- Control

OVERVIEW

Background

The extrusion process is a critical operation with a direct impact on material cost, productivity, delivery performance, and customer satisfaction. Currently, the process experiences a scrap rate of approximately 6%, resulting in significant material wastage, increased rework, and higher operational costs. This level of scrap translates to an estimated monthly loss of USD 5,000, while also affecting production efficiency and on-time delivery. Addressing scrap reduction is essential to improve process stability, reduce the cost of poor quality, and support the organization's operational excellence and profitability objectives.

DEFINE PHASE

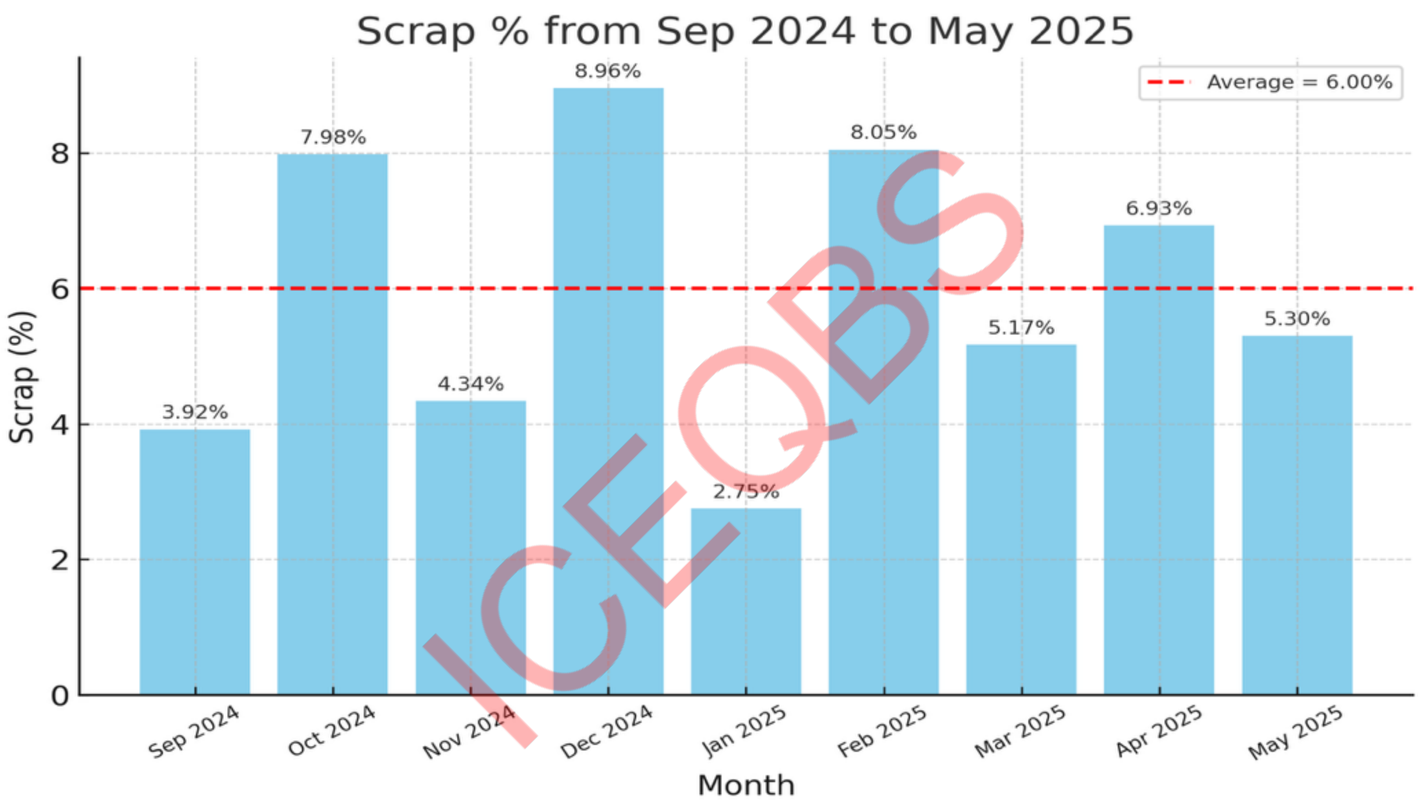


VOC & CTQ

CTQ Tree :

Voice of customer	Critical to X	Primary Metric for improvement
"We need consistent pipe quality with minimal defects."	CTQ (Critical to Quality) – Pipe dimensional accuracy, surface finish, and appearance	**Primary Metric -** Y = % Scrap due to quality defects **Secondary Metric -** Productivity

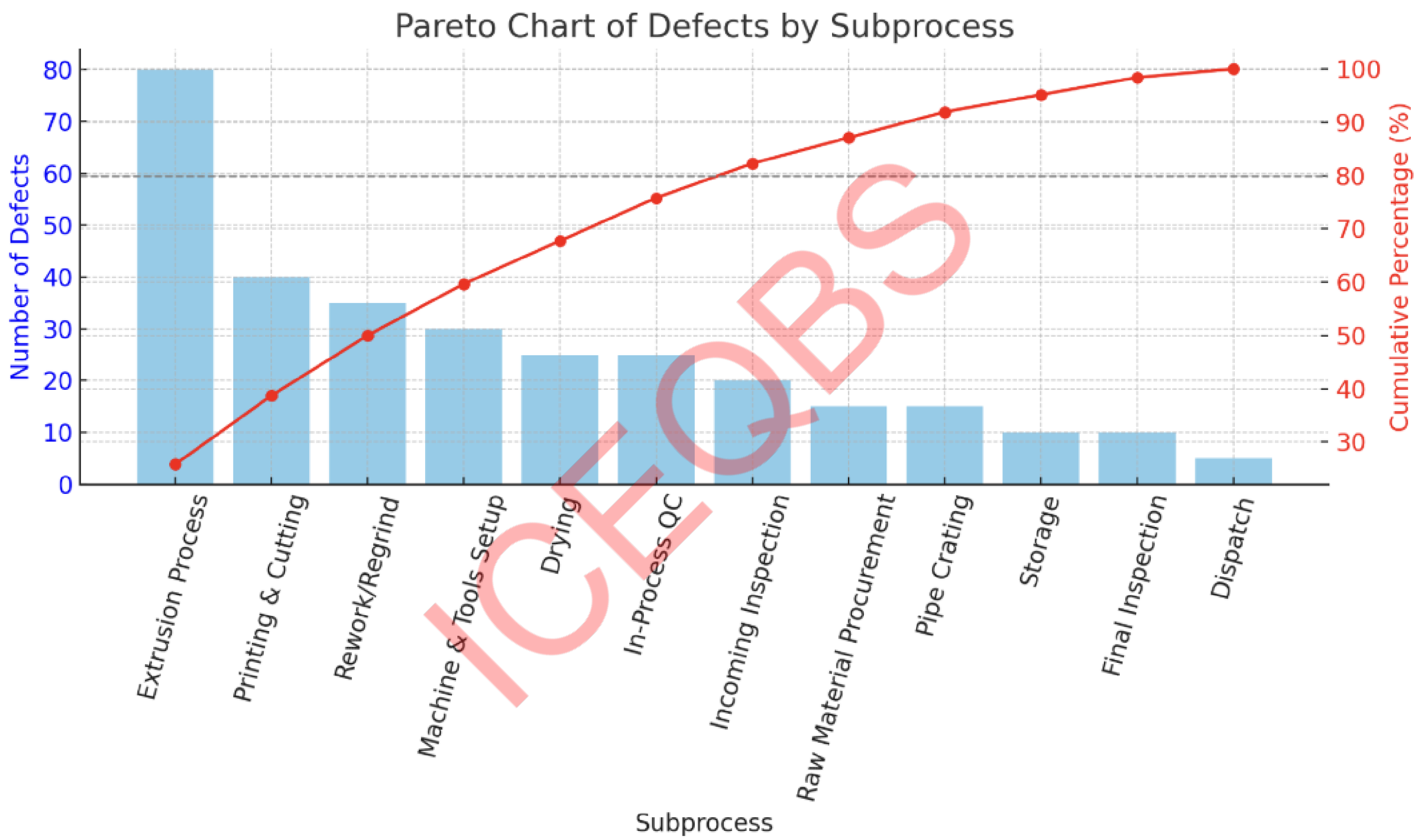
Baseline Performance of Primary Metric (9 months data)



Inference :

- Last 9 months scrap percentage data shows a significant variation and hence ideal problem to be taken up as a Six Sigma Project.

Pareto chart



Inference :

- Extrusion Process contributes substantially for the scrap and included in the scope of the project

Project Charter

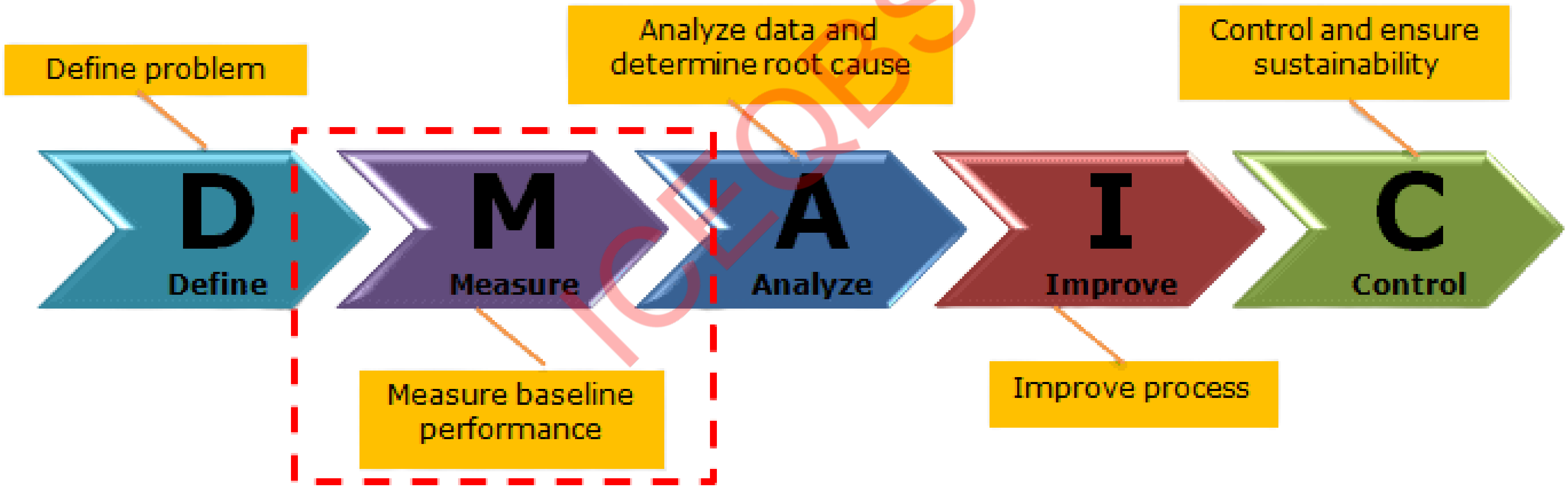
Project Title:	Reduction of Scrap in the Extrusion Process

Project Leader	**Project Team Members:**
Lijin	K Verma S. Nair V Iyer P Singh
Champion/Sponsors:	**Key Stake Holders**
Mr. R. Sharma	Distributors / Dealers Quality Control Maintenance Team Production Planning and Control (PPC)
Problem Statement:	**Goal Statement:**
The current average scrap rate in the extrusion process is approximately 6% of total production volume, leading to material wastage, increased rework, and higher production costs based on the last 6 months data	To reduce the extrusion process scrap rate from 6% to 3% within six months (June – November 2025) by identifying and controlling key process variables affecting material waste.
Secondary Metric	**Assumptions Made:**
Productivity	Stable production volume and product mix during the project period Availability of accurate process and scrap data

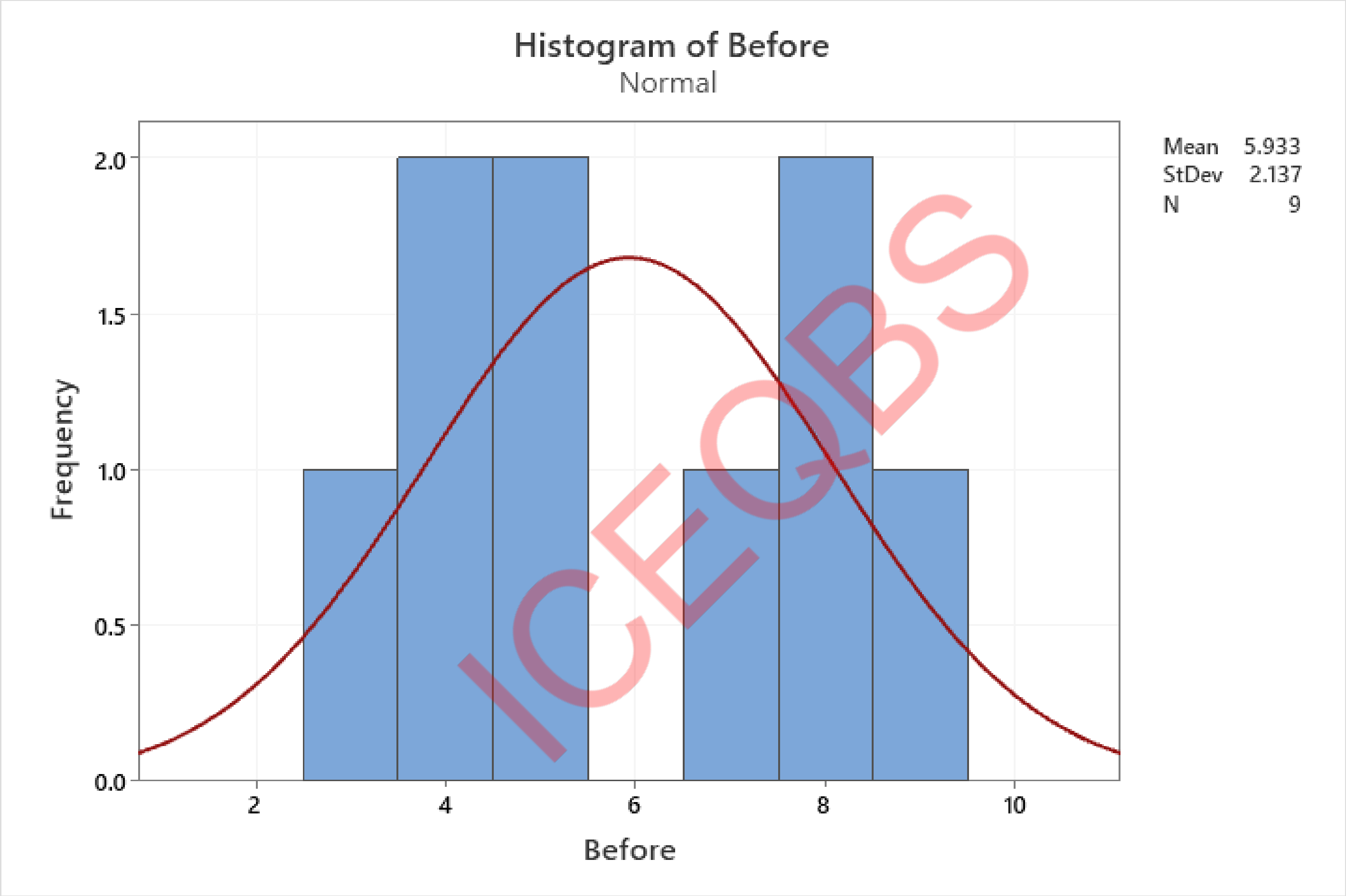
Project Charter

Tangible and Intangible Benefits:	Risk to Success:
Annual cost savings of approximately **USD 60,000** from scrap reduction Reduced material wastage and rework costs Improved process discipline and standardization Enhanced operator capability and ownership	Raw material quality variation affecting extrusion stability Machine condition and maintenance-related issues
In Scope:	**Out of Scope:**
Extrusion line operations (material feeding, temperature control, puller speed, die setting, and pipe cooling). - Process parameters and operator practices directly influencing scrap generation.	- Upstream processes (raw material procurement, compounding). - Downstream processes (printing, cutting, packaging and despatch).
Signatories:	**Project Timeline:**
Sponsor Project Leader Process Engineer	6 months

MEASURE PHASE



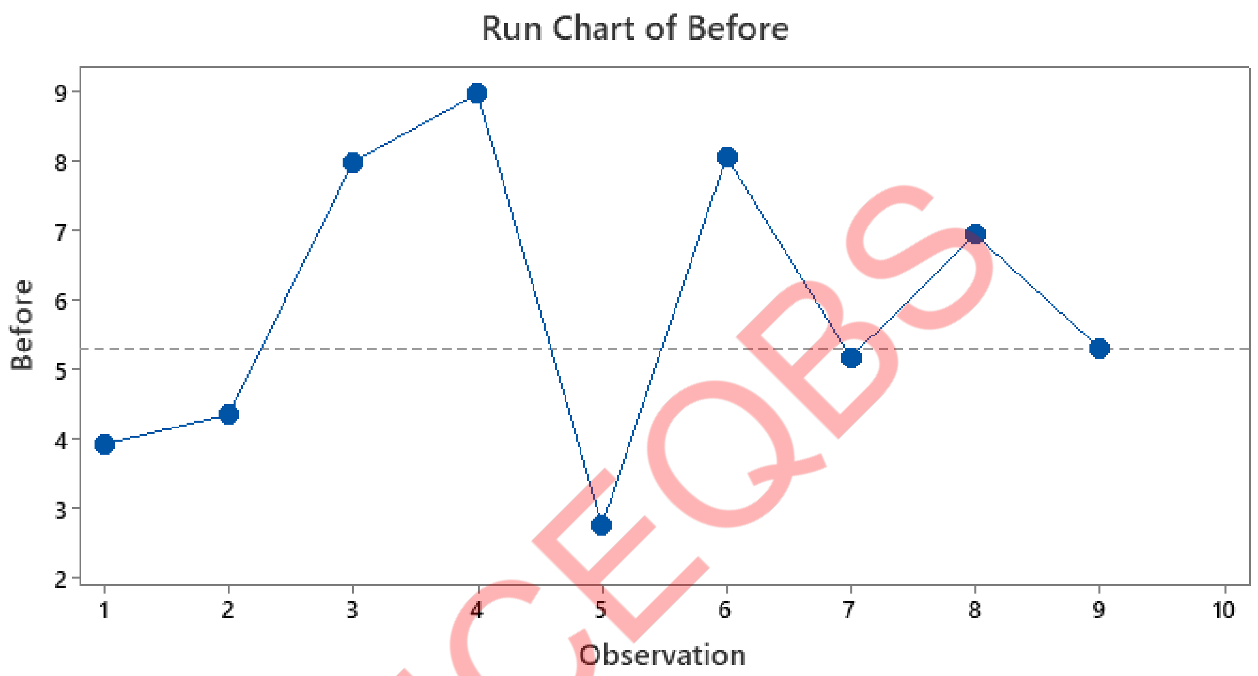
Data collection – Histogram (Before improvement)



Inference :

- Data is normally distributed over the mean

Data collection – Run Chart (Before improvement)

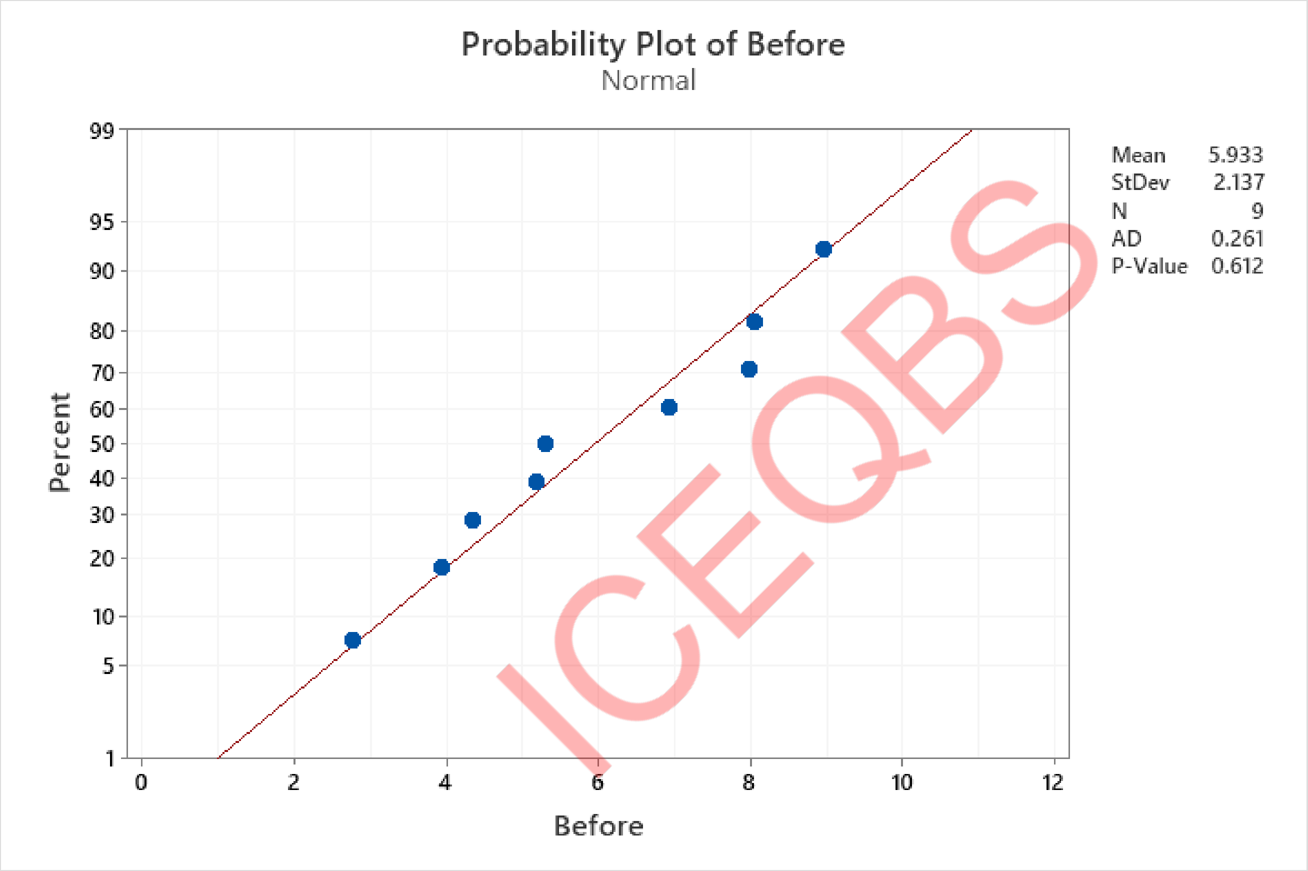


Number of runs about median:	7	Number of runs up or down:	6
Expected number of runs:	5.4	Expected number of runs:	5.7
Longest run about median:	2	Longest run up or down:	3
Approx P-Value for Clustering:	0.870	Approx P-Value for Trends:	0.616
Approx P-Value for Mixtures:	0.130	Approx P-Value for Oscillation:	0.384

Inference :

P > 0.05 – No special causes in the process. Data can be used for further analysis

Data collection – Normality plot (Before improvement)



Inference :

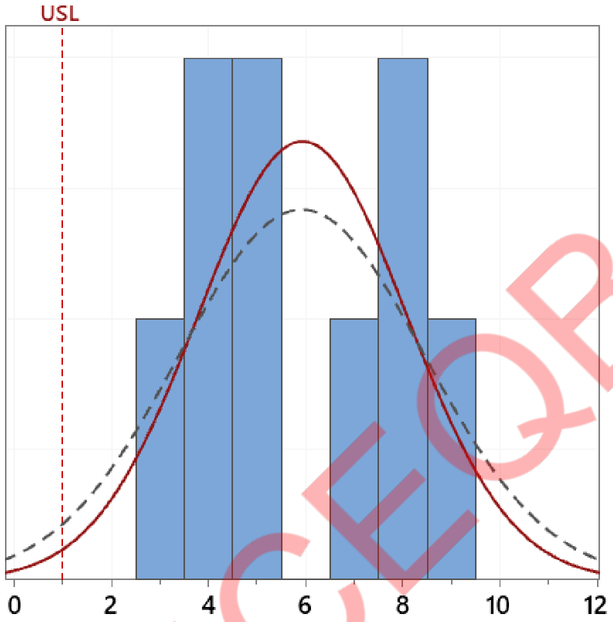
- P > 0.05 in all scenarios, thus all the data is normally distributed

Process Capability (Before improvement)

Process Capability Report for Before

Process Data

LSL	*
Target	*
USL	1
Sample Mean	5.93333
Sample N	9
StDev(Overall)	2.13696
StDev(Within)	2.52881



— Overall
- - - Within

Overall Capability

Pp	*
PPL	*
PPU	-0.77
Ppk	-0.77
Cpm	*

Potential (Within) Capability

Cp	*
CPL	*
CPU	-0.65
Cpk	-0.65

Performance

	Observed	Expected Overall	Expected Within
PPM < LSL	*	*	*
PPM > USL	1000000.00	989516.41	974462.56
PPM Total	1000000.00	989516.41	974462.56

The actual process spread is represented by 6 sigma.

Inference :

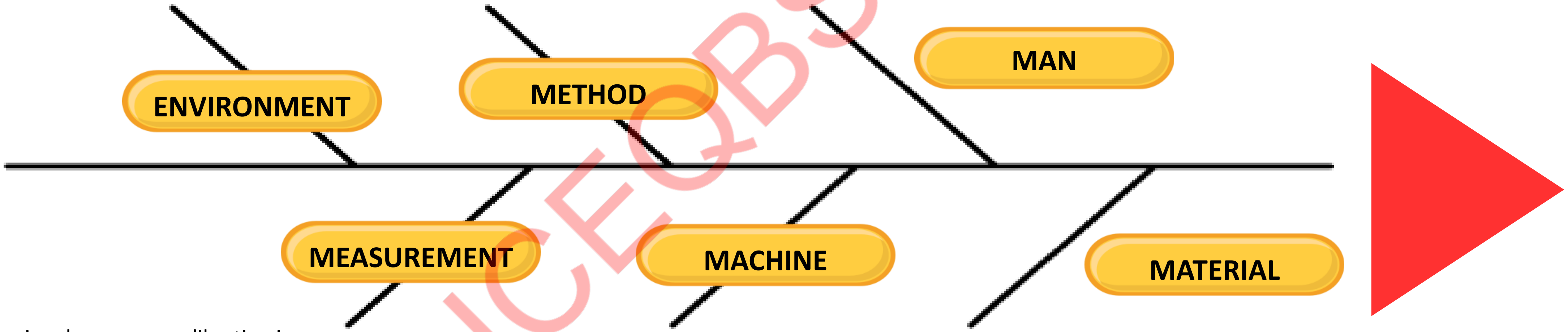
- The process spread is much wider than the specification limits, confirming an unstable and high-risk process requiring immediate improvement and control.

Fish Bone Diagram

1. Fluctuating ambient temperature or humidity
2. - Dust or foreign particle contamination near extruder
3. - Inadequate ventilation or cooling water temperature variation

1. Non-standardized startup and shutdown procedures
2. - Uncontrolled process parameters (temperature, pressure, speed)
3. - Inconsistent die cleaning and maintenance schedule

1. Improper die setup or alignment by operators
2. - Inadequate training on extrusion parameters
3. - Failure to monitor temperature and pressure consistently



1. Inaccurate dimensional gauges or calibration issues
2. - Infrequent in-process inspection
3. - Improper measurement technique by QC staff

1. - Inconsistent extruder temperature control
2. - Worn-out screw or barrel affecting melt uniformity
3. - Cooling system malfunction (chiller or vacuum tank)

1. - Moisture content in raw materials not properly removed
2. - Poor quality resin or inconsistent lot quality
3. - Incorrect additive or pigment mixing ratio

Common and Special causes

Common Causes

- Inadequate training on extrusion parameters
- Improper die setup or alignment
- Inconsistent extruder temperature control
- Moisture content in raw materials
- Poor quality resin or inconsistent lot quality
- Incorrect additive or pigment mixing ratio
- Non-standardized startup/shutdown procedures
- Uncontrolled process parameters
- Inaccurate dimensional gauges
- Infrequent in-process inspection
- Fluctuating ambient temperature or humidity
- Dust or foreign particle contamination

Special Causes

- Cooling system malfunction
- Worn-out screw or barrel
- Puller speed synchronization issue
- Frequent machine breakdowns
- Contamination in material hopper or dryer
- Excessive regrind usage
- Inadequate changeover procedures
- Die cleaning or maintenance not performed as scheduled
- Power fluctuations affecting heater zones
- Delayed feedback on defect detection

3M Analysis for Waste

MUDA

1. Excess material scrap due to incorrect die temperature settings.
2. Idle machine time during setup changes or material waiting.
3. Rework/regrind processing of defective pipes instead of first-time quality output.

Mura

1. Inconsistent extrusion speed, causing variation in wall thickness.
2. Fluctuating cooling water temperature, leading to dimensional instability.
3. Irregular inspection frequency, resulting in missed or delayed defect detection.

Muri

1. Operators handling multiple machines simultaneously, leading to fatigue and errors.
2. Overloading extruder capacity to meet production targets, stressing equipment.
3. Frequent manual adjustments due to unstable process control or poor automation.

8 Wastes Analysis

Defects	• Pipes with surface marks, dimensional variation, or ovality issues. • Scraps generated from incorrect temperature or speed settings.
Overproduction	• Producing more pipes than customer demand. • Running the extruder during downtime or maintenance just to “keep it busy.”
Waiting	• Idle time while waiting for raw materials or tools. • Machine stoppage due to delayed tool or die setup.
Non-Utilized Talent	• Skilled operators not involved in process improvement discussions. • Lack of training or empowerment for staff to suggest quality improvements.
Transportation	• Moving raw materials or finished pipes multiple times between storage and production areas. • Shifting regrind material manually from extrusion to rework area.
Inventory	• Storing large volumes of raw material near the extrusion line. • Excess WIP (pipes waiting for cutting or inspection).
Motion	• Operators frequently walking to fetch tools, gauges, or material samples. • Manual handling of heavy dies due to poor workstation layout.
Overprocessing	• Higher wall thickness of pipes than the minimum customer requirement. • Additional manual inspection when automated gauges are available.

Action Plan for Low Hanging Fruits

Area of Focus	Issue Identified	Lean Tool / Approach	Action to be Taken	Expected Benefit
Machine (Special Cause)	Frequent extruder temperature fluctuation	TPM (Total Productive Maintenance)	Calibrate sensors and implement daily machine check sheet	Improved stability, reduced scrap
Machine (Special Cause)	Cooling system malfunction	5 Why + Visual Management	Identify root cause, label valves & flow direction	Reduced dimensional variation
Method (Special Cause)	Non-standard die setup process	Standard Work (SOP)	Create and display standardized setup checklist.	Faster setup, fewer defects
Material (Special Cause)	Moisture in resin	Poka-Yoke / 5S	Use temp display. Ensure dryers are cleaned regularly	Reduced bubble defects, less scrap

Action Plan for Low Hanging Fruits

Area of Focus	Issue Identified	Lean Tool / Approach	Action to be Taken	Expected Benefit
Muda – Overproduction	Producing excess beyond schedule	Pull System / Kanban	Implement visual production control board	Lower WIP, reduced inventory
Muda – Waiting	Idle time for material loading	SMED / 5S	Pre-stage material near extruder	Less downtime, smoother flow
Mura – Uneven cooling	Temperature variation	SPC (Statistical Process Control)	Track and control cooling water temperature	Stable pipe dimensions
Muri – Overburden	Excess manual lifting of dies	Kaizen + 5S	Provide die trolley or lifting aid	Improved ergonomics, fewer injuries
8 Waste – Motion	Frequent tool search	5S	Shadow boards and tool location tags	Reduced non-value-added motion
8 Waste – Defects	High regrind generation	Root Cause Analysis + Standardization	Optimize extrusion parameters and monitor SPC	Reduced rework/scrap
8 Waste – Inventory	Excess raw material near line	Visual Control / FIFO	Designate marked storage areas	

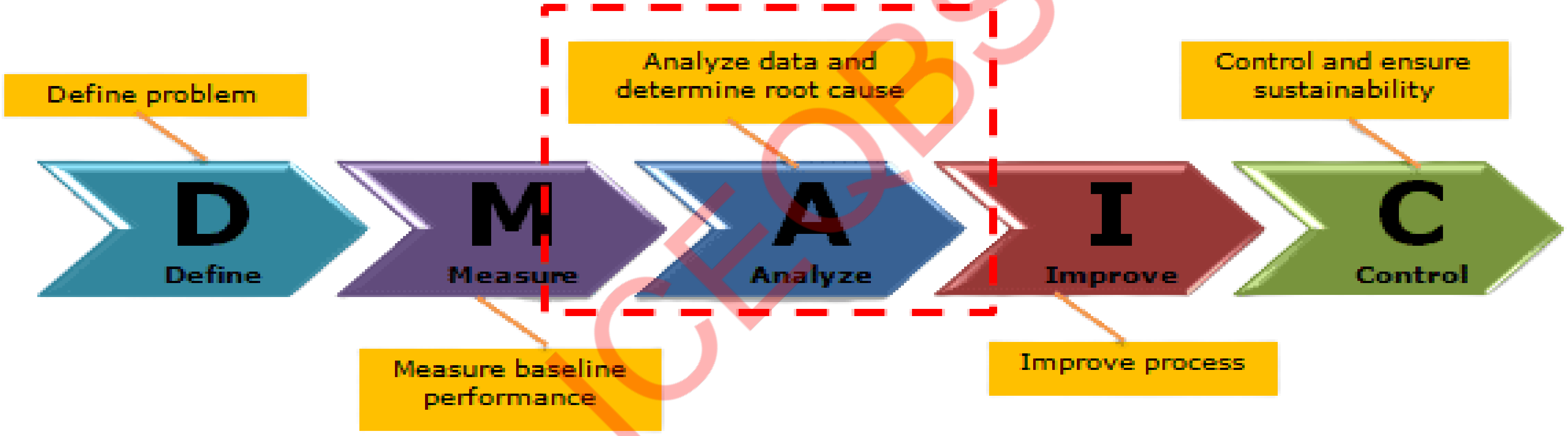
Top 12 Prioritized Root Causes (Based on Net Score)

Root Cause	Score
Inaccurate process settings at start up	360
Barrel/Die Temperature Variation	276
Improper Die Setup	276
Inconsistent Material Feed Rate	276
Worn Screw/Barrel	258
Puller Speed Fluctuation	252
Cooling Water Temperature Variation	252
Cooling Line Blockage	252
Resin Moisture Content	228
Improper Dryer Operation	228
Inaccurate Gauging / QC Delay	264
Excess Regrind Usage	198

Data Collection Plan

S. No.	Root Cause (Input)	Data to be Collected	Measurement Method / Instrument	Data Source / Location	Purpose / Remarks
1	Inaccurate Process Settings at Start-Up	Actual vs. standard machine settings (temperature, pressure, speed) during start-up	Machine control panel readings; setup checklists	Production line; process sheet	To verify adherence to standard startup parameters and reduce variation
2	Barrel/Die Temperature Variation	Actual barrel and die temperature readings across zones	Digital temperature sensors / data logger	Extruder temperature control panel	To detect temperature fluctuation trends and identify control issues
3	Improper Die Setup	Die alignment, centering, and clearance data	Visual inspection; alignment gauge / dial indicator	Setup area; maintenance log	To confirm die setup accuracy and uniform product dimensions
4	Inconsistent Material Feed Rate	Feed rate (kg/hr) vs. target; hopper load variations	Weighing system data; load cell readings	Feed system logs / PLC	To maintain consistent material input and avoid thickness/weight variation
5	Worn Screw/Barrel	Screw and barrel wear measurements (diameter, clearance)	Vernier / micrometer readings; maintenance inspection reports	Maintenance workshop	To determine wear level and plan timely replacement
6	Puller Speed Fluctuation	Actual vs. set puller speed data	Tachometer / PLC speed logs	Extrusion line control system	To maintain stable pulling speed and dimensional consistency

ANALYSE PHASE



Analyse – Hypothesis testing

Regression Analysis: Scrap_Percent versus Inaccurate process settings

Regression Equation

Scrap_Percent = -0.274 + 0.6257 Barrel/Die Temperature Variatio
+ 0.3928 Inconsistent Material Feed Rate
+ 0.555 Cooling Water Temperature Varia

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-0.274	0.741	-0.37	0.714	
Barrel/Die Temperature Variatio	0.6257	0.0367	17.05	0.000	1.06
Inconsistent Material Feed Rate	0.3928	0.0527	7.45	0.000	1.10
Cooling Water Temperature Varia	0.555	0.143	3.89	0.001	1.05

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.569415	94.21%	93.54%	91.87%

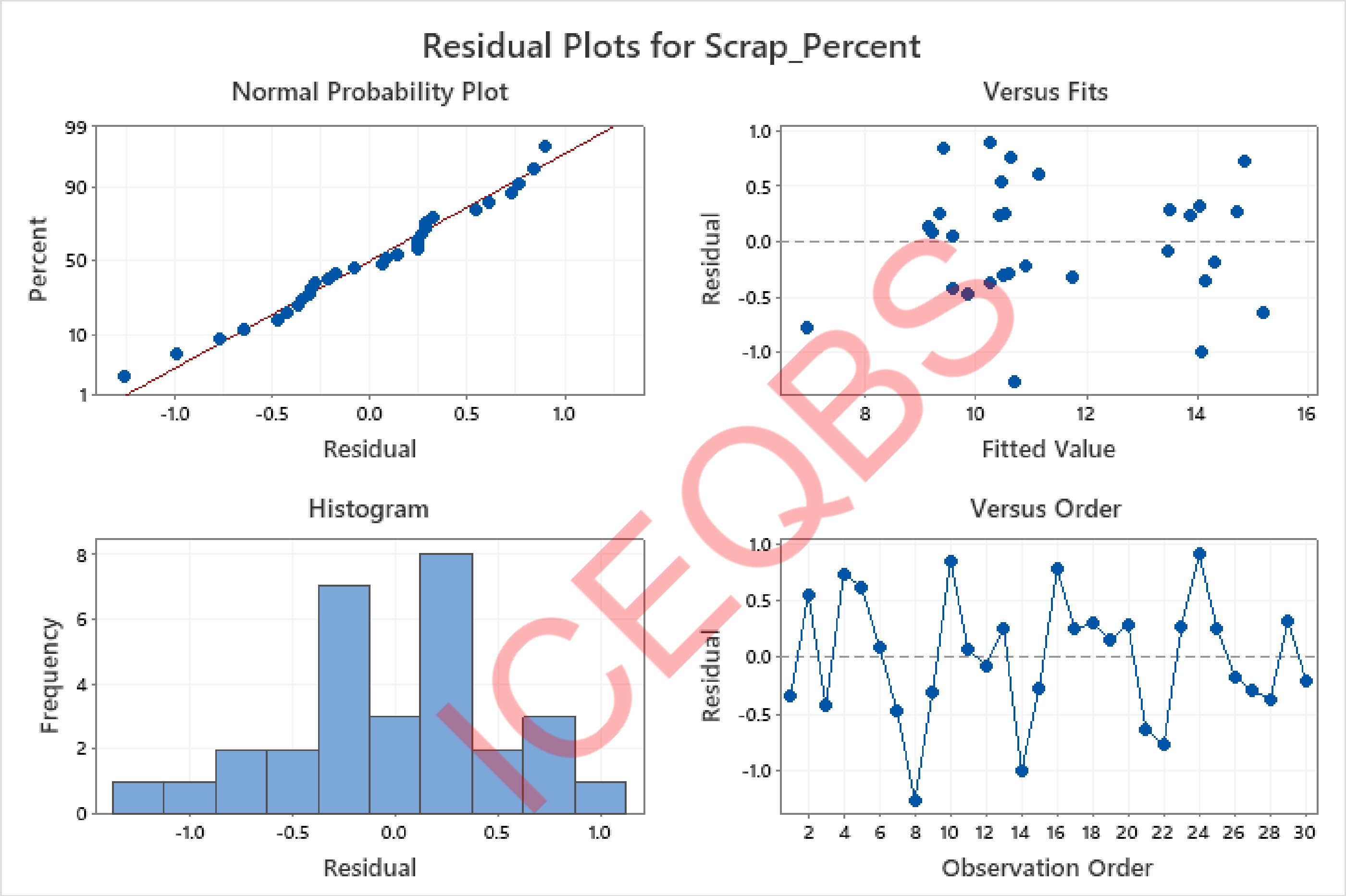
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	137.098	45.6995	140.95	0.000
Barrel/Die Temperature Variatio	1	94.204	94.2042	290.54	0.000
Inconsistent Material Feed Rate	1	18.006	18.0061	55.53	0.000
Cooling Water Temperature Varia	1	4.899	4.8993	15.11	0.001
Error	26	8.430	0.3242		
Total	29	145.529			

Inference :

- Since $p < 0.05$, thus not all means are equal

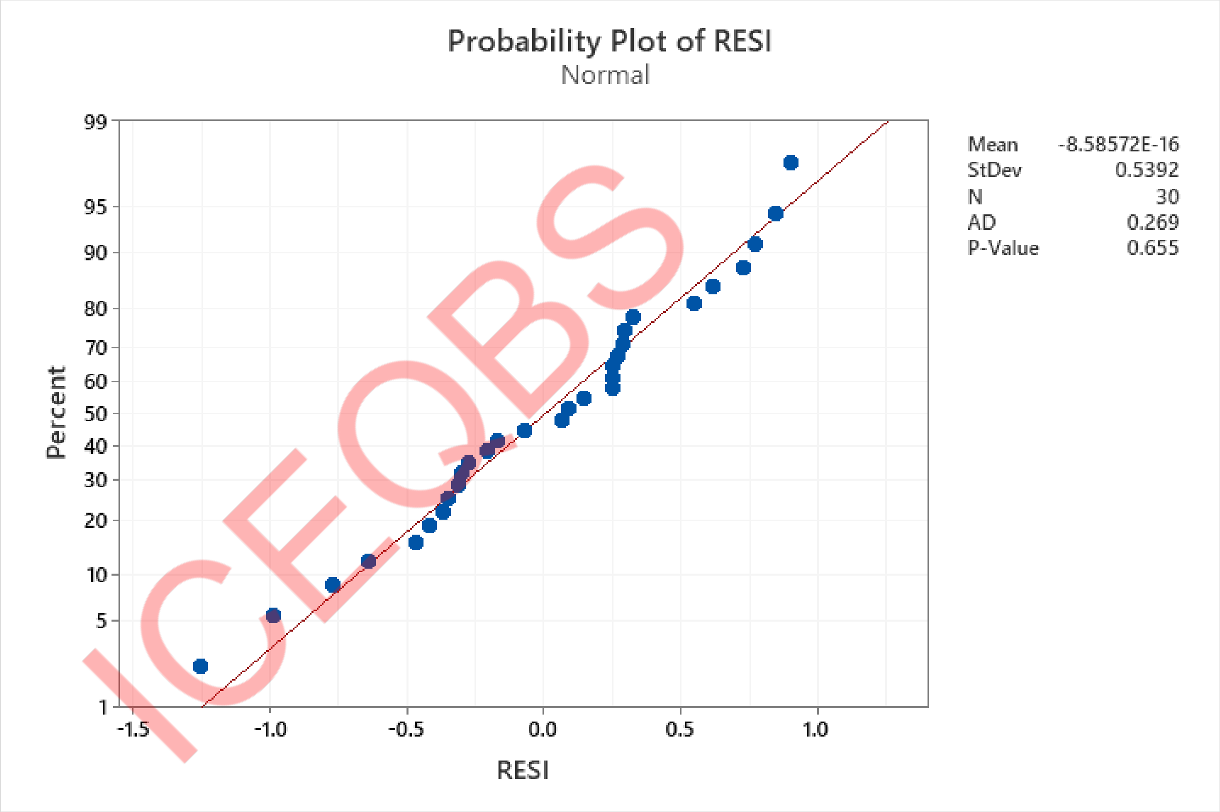
Analyse – Hypothesis testing



Inference :

- Data follow an approximately **normal distribution**, indicating the model assumptions are valid

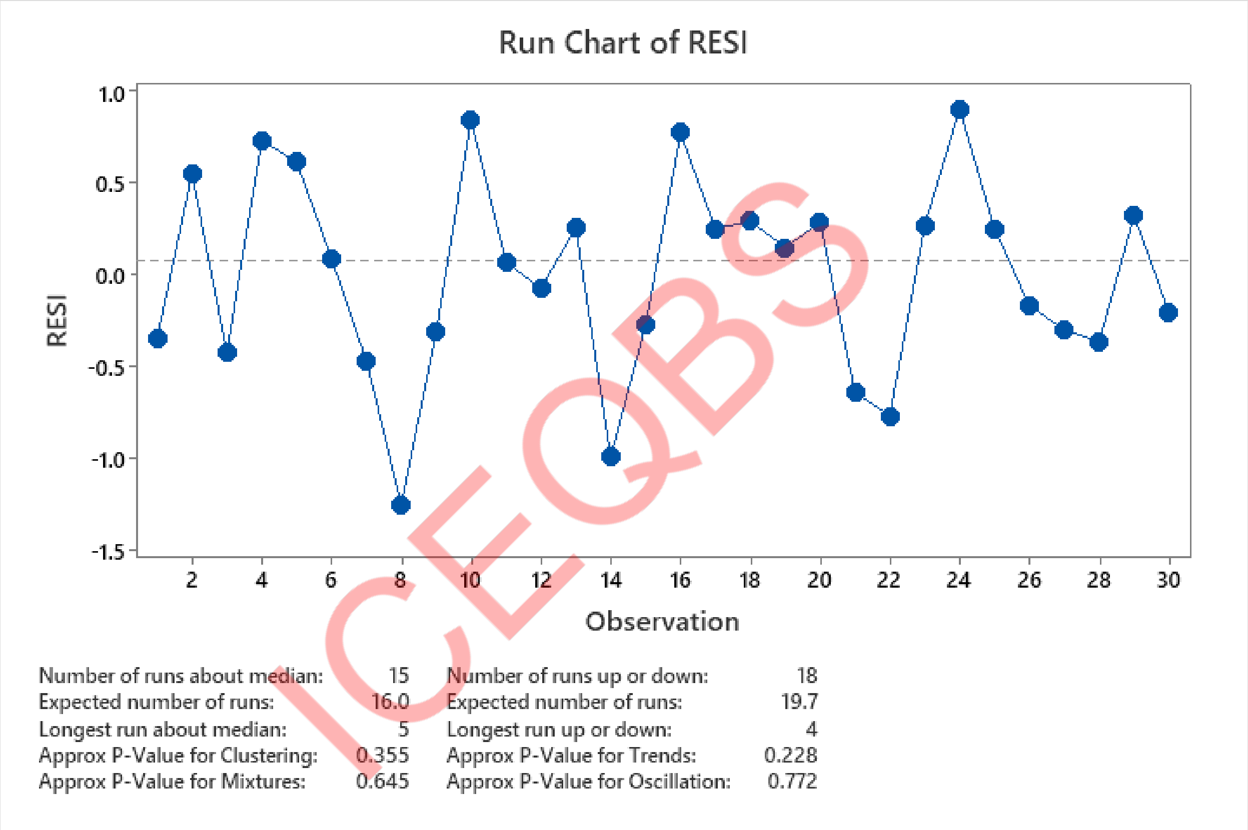
Analyse – Hypothesis testing



Inference :

The Anderson–Darling test **p-value = 0.655 (> 0.05)** confirms normality, validating the model assumptions and reliability of subsequent analysis.

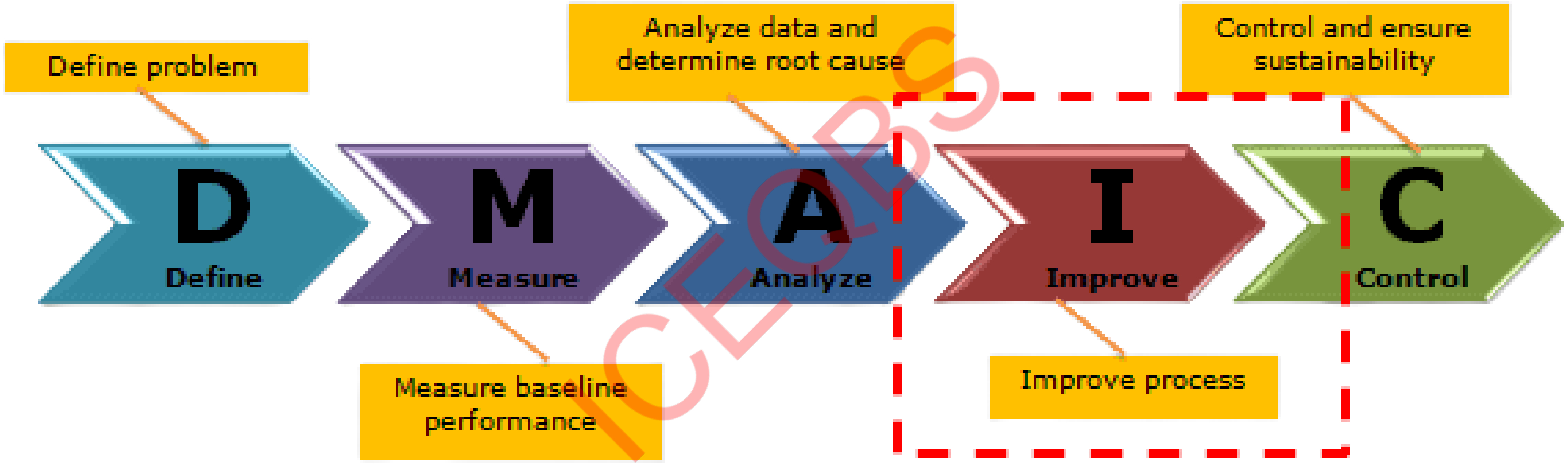
Analyse – Hypothesis testing



Inference :

All run test p-values are **greater than 0.05**, confirming the absence of non-random patterns and validating process consistency.

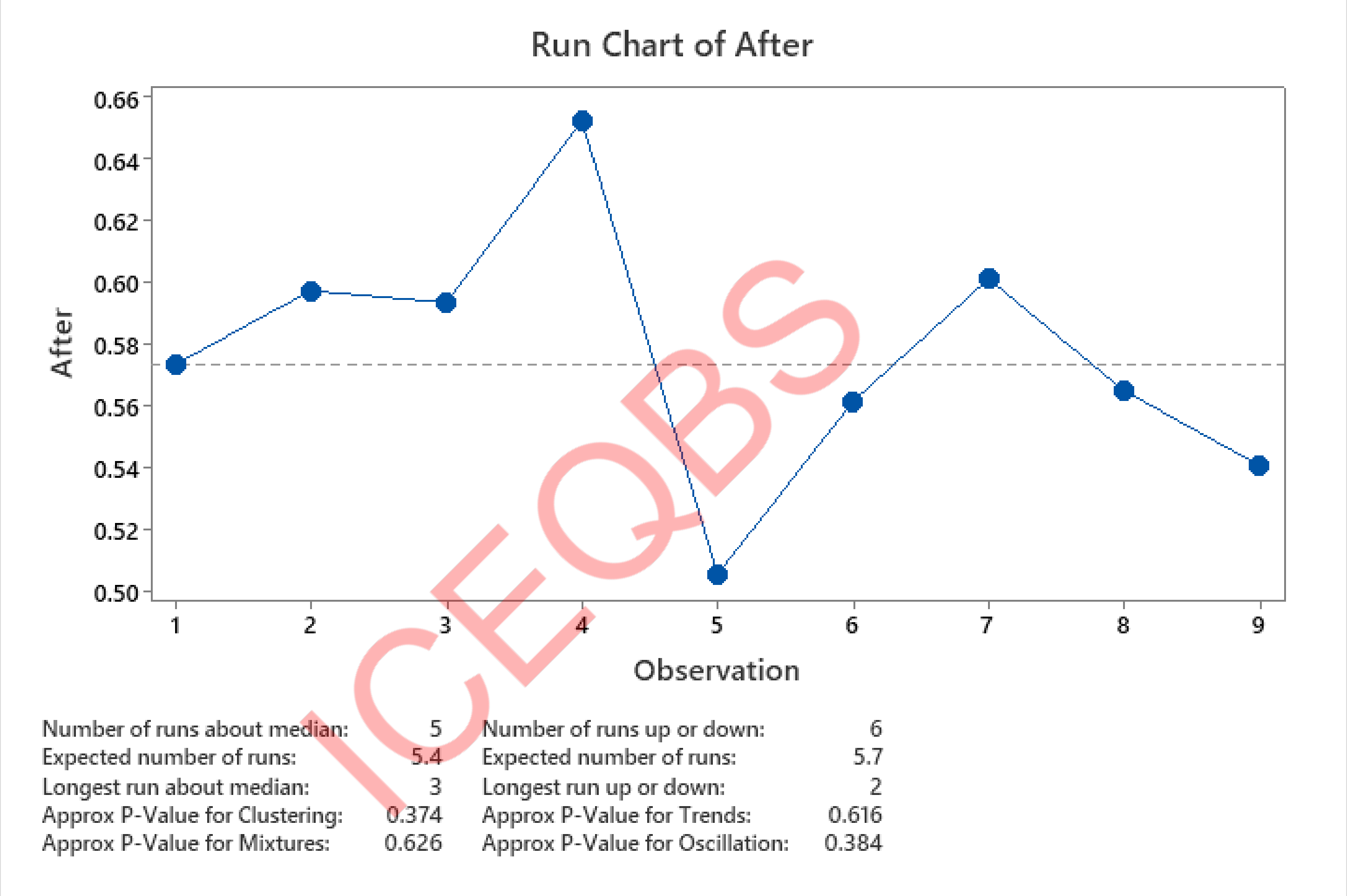
IMPROVE PHASE



Improve

#	Critical Root Cause Addressed	Improvement Action	Implementation Details (How)	Owner	Expected Impact on Scrap
1	Barrel / Die Temperature Variation	Standardize temperature set-up with control limits	• Freeze DOE-optimized temperature setpoints • Define upper & lower control limits (±1 °C) • Lock PLC parameters with supervisor authorization • Include temperature ramp-up SOP for startup	Process Engineer	Reduces melt instability, dimensional defects
2	Barrel / Die Temperature Variation	Closed-loop temperature control & sensor calibration	• Introduce auto-PID tuning for barrel & die zones • Calibrate thermocouples monthly • Replace slow-response or drifting sensors • Add alarm for deviation > 1 °C	Maintenance	Prevents hidden variation during long runs
3	Inconsistent Material Feed Rate	Gravimetric feeder with feed-rate poka-yoke	• Implement gravimetric feeding instead of volumetric • Define acceptable feed-rate window (DOE optimum) • Interlock line start if deviation > ±2% • Display live feed-rate trend at operator panel	Production / Automation	Stabilizes output rate and wall thickness
4	Inconsistent Material Feed Rate	Material handling & hopper management standardization	• Define max hopper refill height & refill frequency • Eliminate manual top-ups during run • Introduce FIFO resin loading SOP • Visual controls for "refill allowed / not allowed"	Production Supervisor	Eliminates short-term feed surges
5	Cooling Water Temperature Variation	Dedicated cooling loop with temperature & flow control	• Install inline chiller with ±0.5 °C control • Add flow & temperature sensors per cooling zone • Prevent mixing with other utility users • Daily check sheet for cooling parameters	Utilities / Maintenance	Improves dimensional stability and ovality

Improve



•All run test p-values are **greater than 0.05**, confirming that the improvement is **consistent and statistically stable over time**.

Improve

•The Anderson–Darling test **p-value = 0.772 (> 0.05)** confirms normality, indicating a stable and predictable improved process suitable for capability analysis and control.

Improve

Two-Sample T-Test and CI: Before, After

μ_1: population mean of Before
μ_2: population mean of After
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Before	9	5.93	2.14	0.71
After	9	0.5769	0.0414	0.014

Estimation for Difference

Difference	95% CI for Difference
5.356	(3.714, 6.999)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
7.52	8	0.000

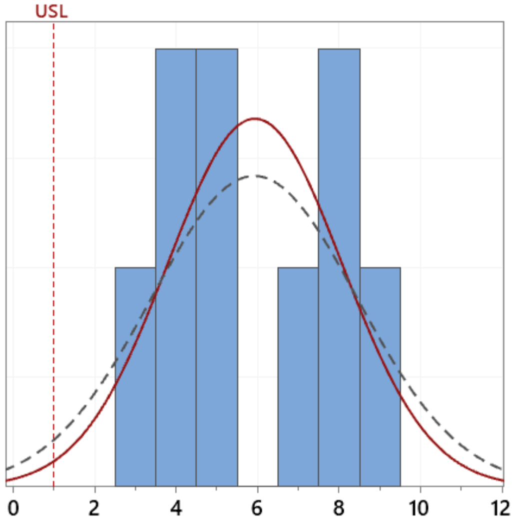
Inference:
Inference (Two-Sample T-Test – Before vs After):
The mean scrap level reduced significantly from **5.93 (Before)** to **0.5769 (After)**, showing a substantial improvement.
The **p-value = 0.000 (< 0.05)** confirms the reduction is **statistically significant**, and the 95% CI for the mean difference **(3.714, 6.999)** does not include zero, validating the effectiveness of the improvement actions.

Improve – Process capability – Before & After Improvement

Process Capability Report for Before

Process Data

LSL	*
Target	*
USL	1
Sample Mean	5.93333
Sample N	9
StDev(Overall)	2.13696
StDev(Within)	2.52881



Overall Capability

Pp	*
PPL	*
PPU	-0.77
Ppk	-0.77
Cpm	*

Potential (Within) Capability

Cp	*
CPL	*
CPU	-0.65
Cpk	-0.65

Performance

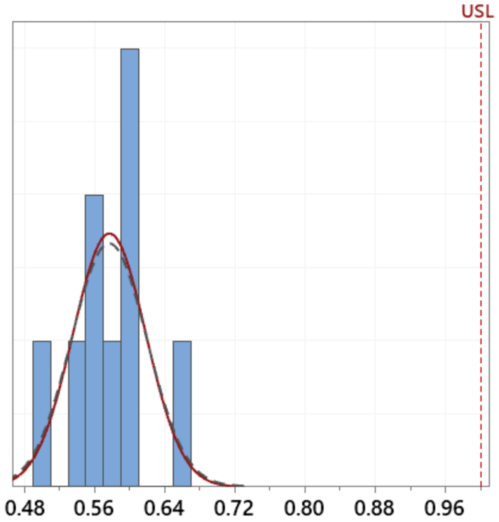
	Observed	Expected Overall	Expected Within
PPM < LSL	*	*	*
PPM > USL	1000000.00	989516.41	974462.56
PPM Total	1000000.00	989516.41	974462.56

The actual process spread is represented by 6 sigma.

Process Capability Report for After

Process Data

LSL	*
Target	*
USL	1
Sample Mean	0.5769
Sample N	9
StDev(Overall)	0.0414026
StDev(Within)	0.0430787



Overall Capability

Pp	*
PPL	*
PPU	3.41
Ppk	3.41
Cpm	*

Potential (Within) Capability

Cp	*
CPL	*
CPU	3.27
Cpk	3.27

Performance

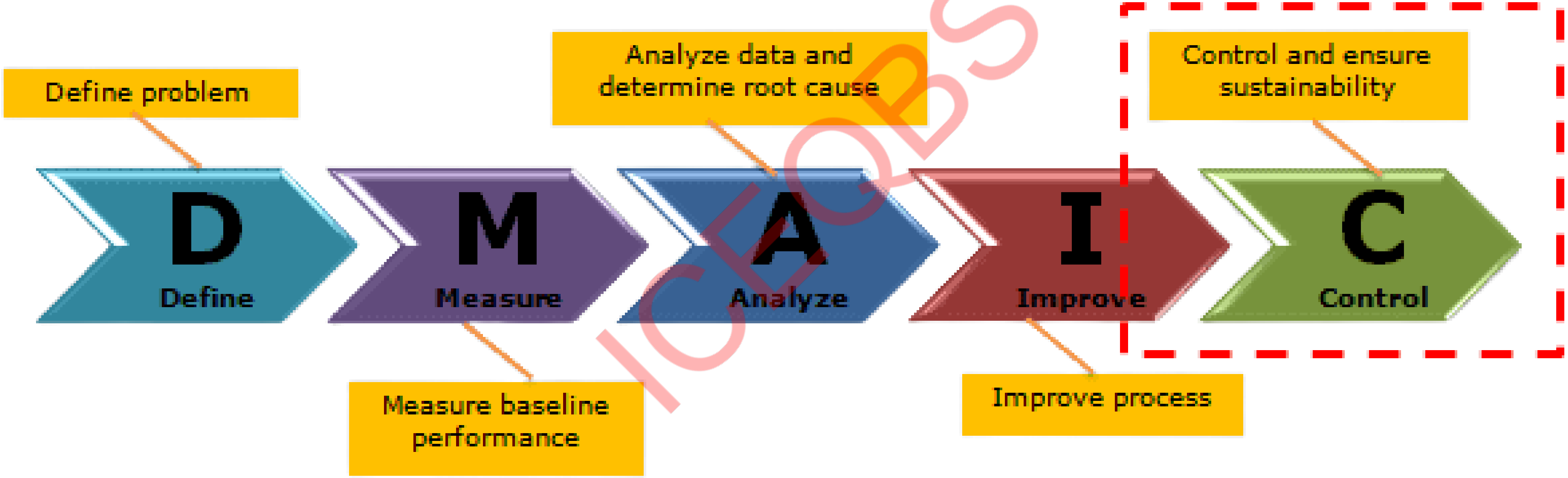
	Observed	Expected Overall	Expected Within
PPM < LSL	*	*	*
PPM > USL	0.00	0.00	0.00
PPM Total	0.00	0.00	0.00

The actual process spread is represented by 6 sigma.

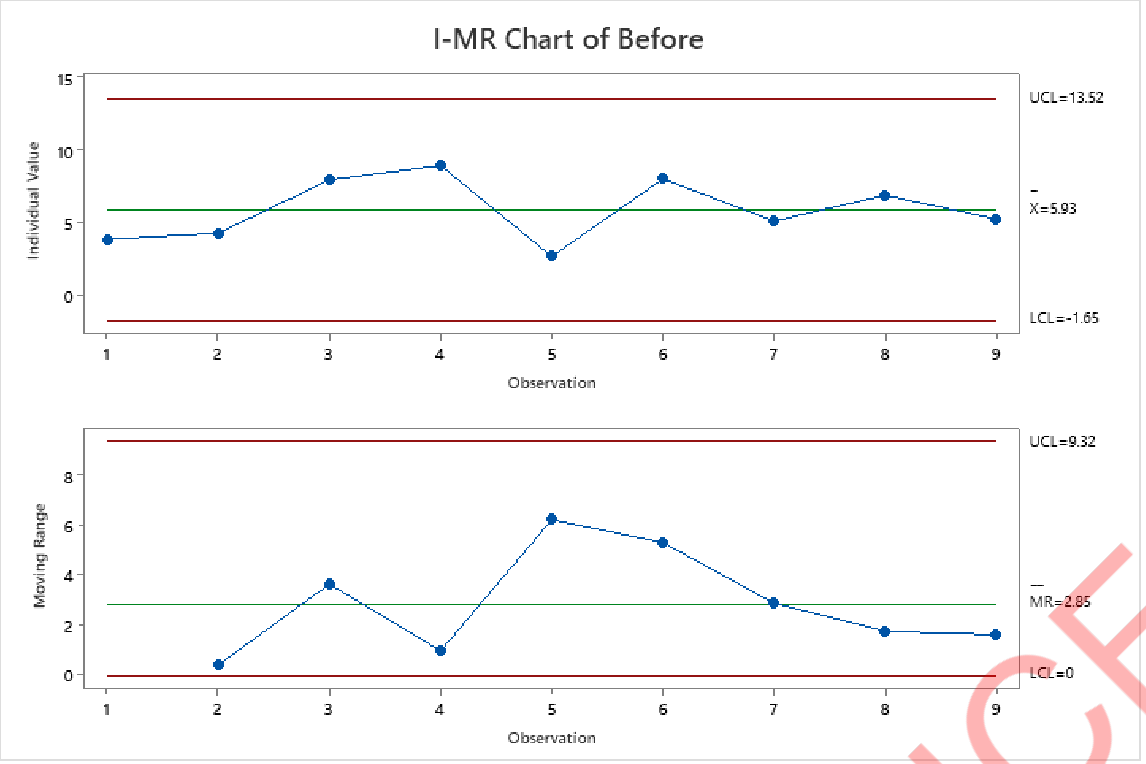
Inference :

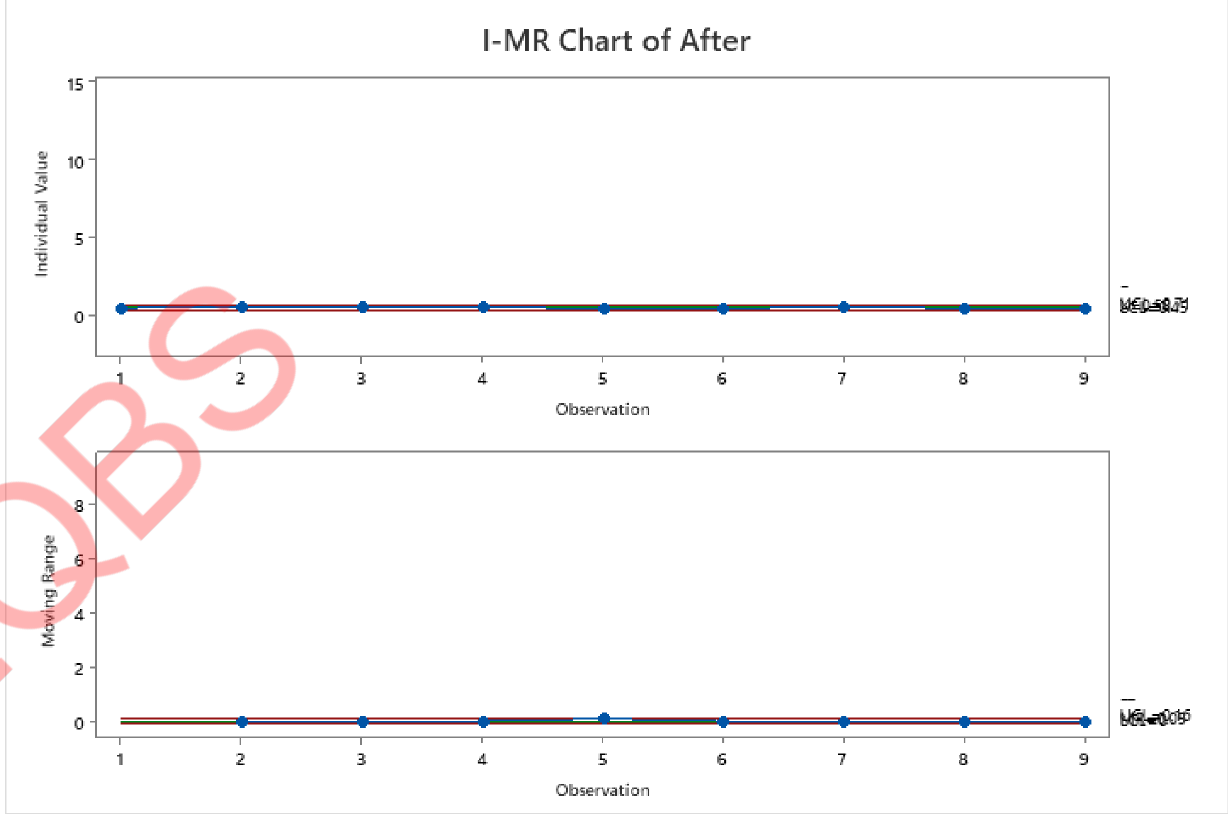
- Before improvement: The process was unstable and incapable, with high variation leading to excessive scrap and defects.
- After improvement: The process is stable and highly capable, with significantly reduced variation, near-zero defects, and sustained performance.

CONTROL PHASE



Improve (Statistical validation for Improvement – I-MR Chart)





Before improvement: The I-MR chart shows high variability and inconsistent moving ranges, indicating an unstable process with special-cause variation.
After improvement: All points are well within control limits with minimal moving range, confirming a stable, well-controlled, and predictable process.

Control Plan

#	5S / Poka-Yoke Type	Problem Prevented	Mechanism Description	Critical Root Cause Addressed
1	Seiton + Poka-Yoke	Wrong temperature settings at startup	• Color-coded temperature setpoint tags (Green = Approved, Red = Do Not Change) • PLC recipe selection restricted to approved DOE recipe only • Startup not allowed unless recipe is selected	Barrel / Die Temperature Variation
2	Seiketsu (Standardization)	Operator-to-operator variation in setup	• Laminated “Golden Setup Sheet” at machine • Displays DOE-optimized values for temperature, feed rate & cooling • One-point lesson for startup & changeover	All three critical root causes
3	Poka-Yoke (Interlock)	Feed rate drift during production	• Interlock stops extruder if feed rate deviates > ±2% for >60 sec • Audible alarm + ANDON signal • Supervisor reset required	Inconsistent Material Feed Rate
4	Seiso + Visual Control	Undetected cooling water instability	• Transparent flow indicators on cooling lines • Green/Red visual bands for acceptable temperature range • Immediate visual detection of blockage or low flow	Cooling Water Temperature Variation
5	Shitsuke (Discipline & Auditing)	Improvement not sustained over time	• Daily 5S audit checklist (≤5 mins) • Temperature, feed rate, cooling parameters included • Weekly trend review linked to scrap KPI	All three critical root causes

Control Plan - FMEA

#	Process Step / Improvement Action	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Controls	D	RPN (S×O×D)	Recommended Proactive Action	Owner	Revised RPN (Expected)
1	Standardized Barrel/Die Temperature Settings	Wrong recipe selected or modified	Melt instability → dimensional scrap	9	Operator overrides PLC setting	5	SOP, manual checks	5	225	PLC recipe lock + supervisor password + alarm on deviation > ±1 °C	Process Engg	72
2	Closed-loop Temperature Control	Temperature sensor drift or failure	Hidden variation → gradual scrap increase	8	Sensor aging, calibration missed	4	Annual calibration	6	192	Monthly calibration schedule + sensor health alarm + spare sensor policy	Maintenance	64
3	Gravimetric Feed Control	Feed-rate fluctuation during run	Wall thickness variation → rejection	8	Manual hopper refilling / feeder clog	6	Operator monitoring	4	192	Feed-rate interlock stop + ANDON alert + no-refill-during-run rule	Production	72
4	Cooling Water Control System	Cooling line blockage or temp drift	Ovality / surface defects	7	Scale buildup, unnoticed flow drop	5	Visual inspection	5	175	Flow sensor + visual flow indicator + daily checklist	Utilities	56
5	Golden Setup & 5S Discipline	Operators skip standard setup	Improvement not sustained over time	9	Lack of discipline / training gaps	4	Training records	6	216	Daily 5S audit + KPI-linked accountability + refresher OPL	Quality	72

Control Plan to sustain improvements

#	Process Parameter / CTQ	Critical Control Method	Control Limits / Target	Reaction Plan (If Out of Control)	Owner
1	Barrel / Die Temperature Variation (°C)	PLC-locked recipe + control chart (I-MR)	Target per DOE; ±1 °C	Stop line → reset approved recipe → verify sensor → restart after QA sign-off	Process Engineer
2	Material Feed Rate Consistency (%)	Gravimetric feeder + interlock	±2% of DOE target	Auto-stop → clear feeder / hopper → restart only after feed stabilizes	Production Supervisor
3	Cooling Water Temperature Variation (°C)	Inline chiller + visual flow indicator	±0.5 °C	Divert product → check chiller & flow → resume after stabilization	Utilities / Maintenance
4	Startup & Changeover Setup Accuracy	Golden Setup Sheet + checklist	100% compliance	Hold production → re-perform setup → supervisor approval required	Shift In-charge
5	% Scrap Performance	Scrap trend chart (daily & weekly)	< 1% average	Trigger root-cause review → corrective action within 24 hrs	Quality

Conclusion

Results after improvement

- This project has successfully transformed the extrusion process into a **stable, capable, and cost-efficient operation**, delivering measurable scrap reduction, sustained control, and long-term business value.